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Survival in the 2.4 GHz ISM Band: Impact on the 802.15.1 Performance

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ABSTRACT
The Steep growth in demand and development of WPAN/WLAN for short range connections has been driven by the need to create ubiquities networks, where one can be connected anywhere at any time making many services and application, just on click. These short range access networks currently exists almost anywhere, at home, at the work place, hotels, hospitals…etc. IEEE 802.15.1(Bluetooth) wireless personal area networks (WPAN) and IEEE 802.11b (Wi-Fi) wireless local area networks (WLAN) share the same 2.4 GHz unlicensed ISM (Industrial, Scientific and Medical) radio frequency band. Without any provisions, mutual interference between these two wireless systems co-located in the same environment.

In this paper, the modeling of IEEE 802.15.1 physical layer in MATLAB Simulink and the coexistence issue is addressed. The coexistence of WLANs and Bluetooth is explained by means of collaborative and non-collaborative methods. This paper focuses on the interference between IEEE 802.15.1 and IEEE 802.11b by examining the performance.

Keywords
802.15.1, 802.11, Bluetooth, WLAN, Interference, Performance

1 INTRODUCTION
Two wireless systems that have experienced the most speedy growth and wide attractiveness are the standard developed by IEEE for wireless local area networks (WLANs), identified as IEEE 802.11, and the Bluetooth as IEEE 802.15.1. Both these systems operate in the 2.4 GHz Industrial, Scientific, and Medical (ISM) radio frequency band (i.e., 2.400-2.4835 GHz).

IEEE 802.11 WLANs are designed to cover huge areas such as offices or buildings. The fundamental building block of the network is the so-called Basic Service Set (BSS), which is composed of several wireless stations and one fixed access point. The access point provides connection to the wired network [1].

WLANs operate at bit-rates as high as 11 Mbps and can use either a FHSS (Frequency Hopping Spread Spectrum) or a DSSS (Direct Sequence Spread Spectrum) [1]. In case of FHSS systems, hopping sequences span over 79 channels, each one 1 MHz wide; while, DSSS systems use a 11 chip Barker sequence and their bandwidth is roughly equal to 20 MHz [2].

Bluetooth can provide a bit rate equal to 1 Mbps. A FHSS scheme is used at the physical level; each master chooses a different hopping sequence so that piconets can operate in the same area without interfering with each other. Hopping frequencies range over 79 frequency channels in the ISM band, each of the channels being 1 MHz wide. The nominal hop dwell time is equal to 625 μs. Sequences are created by generating several sub sequences, each composed of 32 hops. The first sub sequence is obtained by taking 32 hops at random over the first 64 MHz of the frequency spectrum; then the successive 32 MHz are skipped, and the next sub-sequence is randomly chosen among the following 64 MHz. The procedure is repeated until the hopping sequence is completed [4]. A TDD technique is used to transmit and receive data in a piconet: each packet transmitted in a slot corresponds to the minimum dwell time; slots are centrally allocated by the master and alternately used for master and slave transmissions.

In this paper, we first build up flexible model to estimate the performance of IEEE 802.15.1 in presence of IEEE 802.11 WLAN. We use this model to derive results. Our study concentrates on the co-channel interference analysis on the Bluetooth in presence of WLAN. We examine several metrics as the BER and the SNR in presence of the noisy channel. The remaining of this paper is organized as follows: section 2 presents a brief overview of Bluetooth and WLAN. In section 3, a short description of model is presented. Section 4 gives the interference modeling. The performance measurements are presented in section 5. The paper is then concluded in section 6.

2 PROTOCOL OVERVIEW

Bluetooth
The Bluetooth protocol stack is illustrated (See Figure 1) [4]. The Bluetooth specific protocols are SDP, L2CAP, Link Manager, Baseband, and the Bluetooth Radio. Our primary modeling focus is on the characteristics of the RF, Baseband, and L2CAP elements of the stack. Assuming maximum traffic density, it is the characteristics of these sub-layers that dictate network performance in the presence of mutual interference.

The network unit in Bluetooth is called a piconet. A piconet consists of at least two nodes: a master and anywhere from one to seven slaves. The master defines the piconet's pseudo-random frequency hopping sequence and transmission timing, derived from the master's 48 bit address and clock value. The master controls the channel by polling the slave(s) and is always the first to transmit in the TDD cycle. Each slave may only transmit after successful reception from the master.

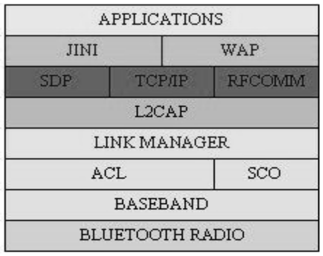

Figure 1: Bluetooth Protocol Stack

The Bluetooth Baseband sub-layer offers two data link layer transmission services, Asynchronous Connection Less (ACL) and Synchronous Connection Oriented (SCO). SCO is a symmetric point-to-point service in which the master transmits on reserved slots. The slave transmits in the following slot. This service was designed to support real time applications, especially voice. The ACL service utilizes a link level ARQ algorithm in which packets are retransmitted until a positive acknowledgement is received by the sender, insuring that ACL frames are not dropped in the physical channel.

Bluetooth Baseband utilizes optional Forward Error Correction for certain packet types. SCO supports 1/3 and 2/3 FEC, while ACL allows for 2/3 FEC only.

The Logical Link Control and Adaptation Protocol (L2CAP) handle application multiplexing, segmentation and reassembly (SAR), and group abstractions.

The Link Manager (LM), also called Link Management Protocol (LMP), is responsible for connection establishment, security, and control. LM messages are filtered out at the receiving node and are not sent up the protocol stack.

The Service Discovery Protocol (SDP) identifies services available by or through a Bluetooth device.

IEEE 802.11b

The IEEE 802.11 standard [9] defines both the physical (PHY) and medium access control (MAC) layer protocols for WLANs. In this sequel, we shall be using WLAN and 802.11b interchangeably. In this work, we focus on the 802.11b specification (DS spread spectrum) since it is in the same frequency band as Bluetooth and the most commonly deployed.

The basic data rate for the DS system is 1 Mbps encoded with differential binary phase shift keying (DBPSK). Similarly, a 2 Mbps rate is provided using differential quadrature phase shift keying (DQPSK) at the same chip rate of 11×10^6 chips/s. Higher rates of 5.5 and 11 Mbps are also available using techniques combining quadrature phase shift keying and complementary code keying (CCK) [10]; all of these systems use 22 MHz channels. The IEEE 802.11 MAC layer specifications, common to all PHYs and data rates, coordinate the communication between stations and control the behavior of users who want to access the network. The Distributed Coordination Function (DCF), which describes the default MAC protocol operation, is based on a scheme known as Carrier Sense Multiple Access, Collision Avoidance (CSMA/CA). Both the MAC and PHY layers cooperate in order to implement collision avoidance procedures. The PHY layer samples the received energy over the medium transmitting data and uses a clear channel assessment (CCA) algorithm to determine if the channel is clear. This is accomplished by measuring the RF energy at the antenna and determining the strength of the received signal commonly known as RSSI, or received signal strength indicator. In addition, carrier sense can be used to determine if the channel is available. This technique is more selective since it verifies that the signal is the same carrier type as 802.11 transmitters. In all of our simulations, we use carrier sense and not RSSI to determine if the channel is busy. Thus, a Bluetooth signal will corrupt WLAN packets, but it will not cause the WLAN to defer transmission.

3 SIMULATION MODEL IN MATLAB

In our studies the simulation model comprises a master transmitter and a slave receiver, a radio channel, 802.11b interfering module, operating in the same environment, thus causing interference (See Figure 2).

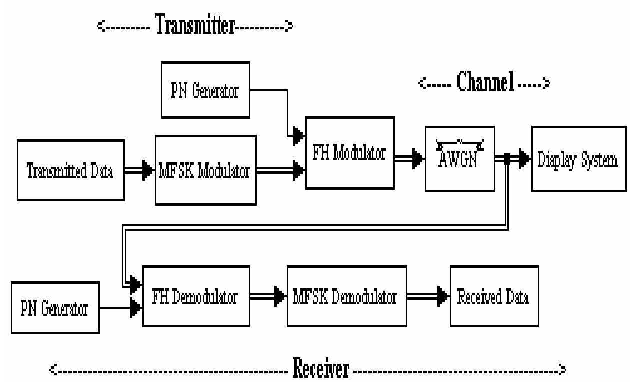

Figure 2: Bluetooth Radio layer Model

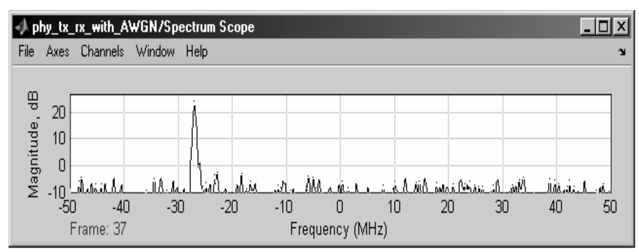

Figure 3: Frequency Hopping Spectrum

For the measurement of errors, error meters are used. The model allows us to record precisely all the physical parameters and changes that affect the Bluetooth transmission thus influencing the performance that we a trying to evaluate.

In the Matlab environment the noisy channel is simulated by an Additive White Gaussian Noise (AWGN) channel (See Figure 4), who's Signal to Noise ratio (SNR) can be controlled.

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4 INTERFERENCE MODELING

The 802.11 is generated by a separate independent block which allows us to control precisely the rate of 802.11 transmissions.

In the simulation we have studied the combined influence of the noisy environment worsened by a neighboring 802.11 transmitting wireless device (See Figure 5). We have also made a point to examine if there is any difference in the performance and the way the BER is affected in different types of packets.

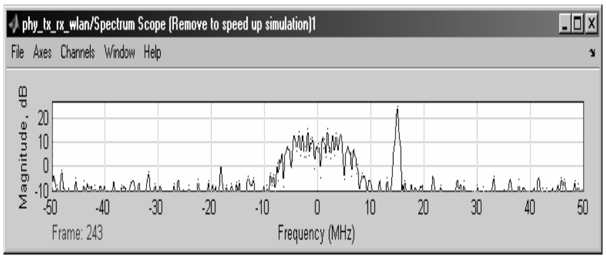

Figure 4: Sharing of the Band by two technologies

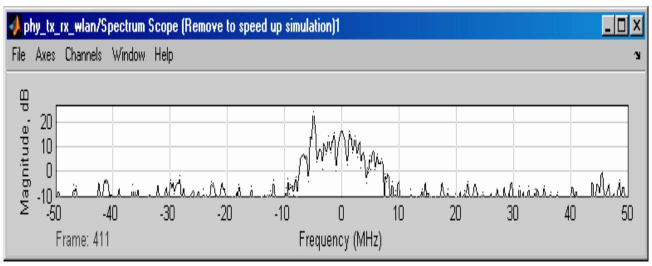

Figure 5: Interference due to IEEE–802.11b WLAN

5 PERFORMANCE MEASUREMENTS

In this scenario, if an IEEE 802.11b (WLAN) device encounters interference from a Bluetooth transmission and subsequently slows its transmission rate; it will then spend more time than before transmitting a packet on a frequency available to Bluetooth, thus having the effect of increasing the likelihood of interference between Bluetooth and 802.11b. Data is not lost, but the data throughput rate may slow to an intolerable level.

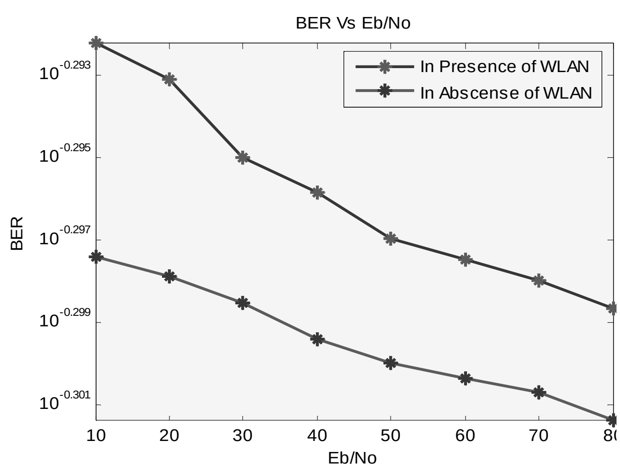

Figure 6: BER Vs En/No With and Without 802.11b

6 INTERFERENCE AVOIDANCE ALGORITHMS

6.1 Collaborative mechanisms

A collaborative coexistence mechanism is defined as one in which the wireless personal area network (WPAN) and the WLAN communicate and collaborate to minimize mutual interference. The following collaborative techniques being considered require that a Wi-Fi device and a Bluetooth device be collocated (i.e. located in the same laptop).

6.1.1 ALTERNATING WIRELESS MEDIUM ACCESS (AWMA)

The IEEE 802.11 WLAN Access Point sends out a beacon at a periodic interval. The beacon period is T_B. AWMA subdivides this interval into two subintervals: one for WLAN traffic and one for WPAN traffic. Fig illustrates the separation of the WLAN beacon interval into two subintervals. The WLAN interval begins just prior to the WLAN target beacon transmit time (TBTT). The time from the beginning of the WLAN interval to the TBTT is specified as T_1. The duration of WLAN subinterval is T_{WLAN}. The duration of the WPAN subinterval is T_{WPAN}. The combined duration of these two subintervals must equal the WLAN beacon period. So $T_{WLAN} + T_{WPAN} = T_B$.

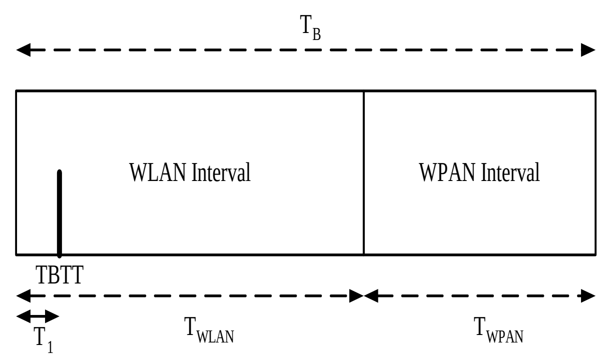

Figure 7: Timing of the WLAN and WPAN subintervals

AWMA requires that all WLAN transmissions are restricted to occur during the WLAN subinterval. Similarly, all WPAN transmissions are restricted to the WPAN subinterval. The WLAN mobile units and the WLAN Access Points all share a common TBTT, so along with shared knowledge of the value of T_1, all WLAN devices must restrict their transmissions to be within the common WLAN subinterval.

The WPAN devices collocated with the WLAN nodes must be the WPAN master device. In particular, if the WPAN device conforms to IEEE 802.15.1 all Asynchronous Connectionless (ACL) data transmissions are controlled by the WPAN master. In particular, WPAN slaves can only transmit ACL packets if in the previous time slot the WPAN slave received an ACL packet. Therefore, the WPAN master must end transmission long enough before the end of the WPAN interval so that the longest slave packet (e.g. a five-slot 802.15.1 packet) will complete its transmission prior to the end of the WPAN interval

6.1.2 FREQUENCY NULLING

Since the Bluetooth signal has a bandwidth of approximately 1MHz, it can be considered a narrowband interferer for the 22MHz wide 802.11b signal. The basic idea of the suppression technique is to put a null in the 802.11b's receiver at the frequency of the Bluetooth signal. However, since Bluetooth is hopping to a new frequency for each packet transmission, the 802.11b receiver needs to know the frequency hopping pattern, as well as the timing, of the Bluetooth transmitter. This knowledge is obtained by employing a Bluetooth receiver as part of the 802.11b receiver. The frequency nulling is achieved by means of tap adjustments in a transversal filter (See Figure 8).

Non-Collaborative Mechanisms

A non-collaborative coexistence mechanism is one in which there is no method for the WPAN and WLAN to communicate.

6.1.3 ADAPTIVE FREQUENCY HOPPING (AFH)

Adaptive Frequency Hopping is a non-collaborative technique implemented by Bluetooth radios in order to avoid interference. The AFH algorithm dynamically changes the frequency hopping sequence of the device, thereby restricting the number of channels the Bluetooth node hops across. This allows certain frequency channels to be left open for use by other systems, such as WLAN.

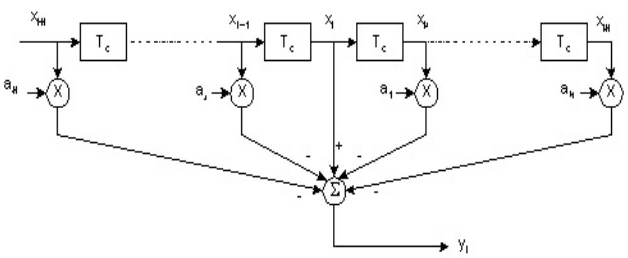

Figure 8: Frequency Nulling Scheme

At this point, it is important to familiarize ourselves with channel estimation criteria. Channel estimation methods include BER calculation, packet loss, or frame error rate measurements performed by each receiver. Each Bluetooth receiver maintains a Frequency Status Table (FST). Frequencies are classified "good" or "bad" depending on whether their packet loss rate is below or above a threshold value respectively. Each slave has its own FST maintained locally. However, the master has in addition to its FST, a copy of each slave's FST. At regular time intervals each slave updates its FST copy kept at the master using a status update message. The master uses the channel information collected in order rearrange the frequency hopping pattern in case of AFH and/or selectively avoid to transmit packets on so-called "bad" frequencies.

In IEEE 802.11 system RSSI (Received Signal Strength Indication) is used internally in a wireless networking card to determine when the amount of radio energy in the channel is below a certain threshold.

6.1.4 ADAPTIVE PACKET SELECTION AND SCHEDULING

Mechanism for the Bluetooth MAC scheduler consisting of two components:

1. Interference Estimation
2. Master Delay Policy

In the *Interference Estimation* phase, the Bluetooth device detects the presence of an interfering device occupying a number of frequencies in the band. In this sequel, interfering devices are assumed to be WLAN DSSS systems.

Use	Frequency Offset	BER_f
✓	0	10^{-3}
✗	1	10^{-1}
✗	2	10^{-2}
✗	3	10^{-1}
	...	
✓	76	10^{-4}
✓	77	10^{-3}
✓	78	10^{-3}

Figure 9: Frequency Status Table

7 CONCLUSION

We presented results on the performance of Bluetooth and WLAN operating in the 2.4 GHz ISM band based on PHY layer model for both the system. The evaluation framework used allows us to study the impact of interference, where two systems are affecting each other.

In this paper, the coexistence issue of Bluetooth and WLAN in the 2.4 GHz ISM band is addressed. The collaborative and non-collaborative methods are suggested to avoid interference.

We are able to illustrate some useful conclusions based on our results.

1. The WLAN represents the worst type of interference for Bluetooth. In addition, the Bluetooth performance seems to degrade.
2. The performance is evaluated in terms of the BER.

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